Renewable and Sustainable Energy Reviews 16 (2012) 2850–2863

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete

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ARTICLE INFO

Article history:
Received 7 April 2011
Accepted 19 February 2012
Available online 22 March 2012

Keywords:
Wind
Park
Turbine
Environmental
Impact
Visual
Noise emission
Bird
Shadow flicker
Electromagnetic interference
Public opinion

ABSTRACT

A review of the wind parks' environmental and human impacts, based on extended research on the most recent relevant bibliography, is carried out in the present paper. The results of former studies are presented on:

- the impact on the aesthetic of the landscape
- the noise emissions
- the impact on birds and wildlife
- the shadow flicker from wind turbines
- the occupation of land
- the wind turbines electromagnetic interference.

In addition, the results of case studies for selected wind parks installed in the Prefecture of Lasithi in Crete, concerning their visual impacts and their noise emissions are presented. A statistical survey implemented in Crete concerning the public opinion on wind parks and wind energy is also presented.

The accomplished tasks indicated:

- There are no serious impacts caused by the installation or operation of wind parks. The wind parks' impacts may be eliminated with the optimum selection of the installation sites and the appropriate siting of the wind turbines.
- People in Crete exhibit a strongly positive attitude towards wind energy and wind parks, although they are not willing to pay a higher price for the electricity produced from wind parks.

A map with the optimum sites for wind parks installation in the Prefecture of Lasithi was constructed, taking into account all possible restrictions concerning the use of land, the environmental conservation and the impacts on human life. This map can constitute a flexible tool for the optimum site selection for a wind park installation, contributing to the elimination of environmental and human impacts of new wind parks, to the minimization of the required project's licensing time and to the limitation of possible negative public reactions.

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2012.02.041

1. Introduction

Wind power is considered as one of the cleanest energy sources, with mild impacts on the environment, on wildlife and on human life, as far as the production of electricity from modern wind turbines is concerned. The impacts on the aesthetic of the landscape, the noise emissions, the impacts on birds and wildlife, the occupation of land, the wind turbines' shadow flicker and the electromagnetic interference are mentioned in relevant former studies as the most serious environmental and human impacts of wind parks. The effect of the abovementioned impacts is always local, namely it is restricted in the vicinity of a wind park's site, unlike the impacts of conventional electricity production technologies (greenhouse gases emissions, nuclear waste), that exhibit a global attribute. The environmental impacts from the most common electricity production technologies are summarized in Table 1. From Table 1 it is obvious that the environmental and human impacts of wind parks are significantly less important compared to the respective impacts of conventional electricity production technologies (thermal or nuclear power plants).

Despite the abovementioned facts, under certain circumstances, the environmental and human impacts of a wind park can be important for the neighbouring area of its installation site. On this occasion, significant negative public reactions may appear during the wind park's licensing, installation or operation [1–4]. Such reactions can only be treated beforehand with the appropriate selection of the wind park's installation site, as well as with carefully planned dissemination policies [5–7].

The present article investigates environmental and human impacts of wind parks. The article aims to evaluate the impacts of wind parks and to investigate the prerequisites for a wind park's mild and secure operation. This aim is approached with the following tasks:

At a first stage, a review of the impacts of wind parks, based on extensive research on the most recent relevant bibliography is fulfilled. With this task, the global experience on the environmental and human impacts of wind parks, as provided by different teams of scientists (engineers, biologists, environmentalists), is gathered.

At a second stage, a case study is fulfilled for the Prefecture of Lasithi, in Crete. This study includes visual impacts evaluation and noise emissions calculation for selected wind parks installed in the Prefecture of Lasithi. The case study is integrated with a statistical survey implemented in Crete about the public opinion concerning wind parks and wind energy.

Finally, following the results of both the former relevant articles and the implemented case study in Crete, a map with the optimum sites for wind parks installation in the Prefecture of Lasithi is constructed, taking into account all possible restrictions concerning the use of land, the impact on human life and the environmental conservation. This map can constitute a flexible decision tool for the optimum site selection for a wind park installation, contributing both to the limitation of the environmental and human impacts of the new wind parks, to the minimization of the required project's licensing time and to the elimination of possible negative public reactions.

2. The environmental and human impacts of wind parks

2.1. Visual impact

Visual impact of wind parks is based on the influence on a landscape's view, caused by the installation of huge technical constructions, especially in sites with a lack of any other human interference. The required network for the produced electricity transportation affects the landscape as well.

The wind turbines' size, in combination with their installation positions (usually at the top of hills or mountains) make them visible even from great distances. Consequently, the influence of wind parks on the landscape is indubitable. The question is whether this influence can be accepted or not. The answer is rather subjective, since it depends on the point of view with which one may face this issue [8]. Sometimes wind turbines may be considered as large and ugly constructions that convert natural landscapes to industrial areas, sometimes as useful and clever machines that produce clean and cheap energy and sometimes as one of the most promising solutions towards the limitation of the operation of the thermal and nuclear power plants, a fact that makes them invaluable and irreplaceable.

The evaluation of the visual impact of a wind park in a landscape is a difficult multi-parametric task [9–13]. Despite the subjective nature of this issue, there are some objective parameters that affect the visual acceptability of a wind park [14]. Generally, these parameters are:

- **The wind park's normal operation**. An important parameter for the acceptance of a wind park is its normal operation. When the wind turbines operate normally, they are considered to serve a purpose, so they are useful. In this case, they may be visually acceptable. On the contrary, when the majority of the wind turbines in a wind park are standing still while the wind blows, the observer's anticipation for the wind turbines' necessity and usefulness is broken. In this case, the impression of the landscape's spoliation without any benefits dominates.
- **The wind park's installation site**. The zone of visual impact of a wind park installed in a flat area in central Europe is less broad than the one of a wind park installed at the top of a hill in a small island in the Aegean Sea. On the other hand, the visual impact of a wind park on the landscape may be considered more intensive in narrow and closed landscapes (a valley in central Europe) rather than in open areas (a hill on a Greek island).
- **The natural aesthetics of the installation area**. The installation of a wind park in the neighbourhood of areas with remarkable natural beauty may cause significant negative reactions. On the

Table 1
Environmental impacts from the most common production technologies of electricity.

Energy source	Production technology	Gas emissions	Other environmental impacts
Coal, oil, natural gas	Thermal power plants	CO_2, NO_x, SO_x, VOC, ash	Exhaustion of reserves, pollution during transportation.
Nuclear fuel	Nuclear power reactors	–	Nuclear waste, nuclear weapons, nuclear accidents.
Biomass	Thermal power plants	CO_2, SO_x, VOC, cinder	Reduction of agricultural production.
Hydro power	Hydroelectric power plants	–	Impact on sensitive biotopes, dangers from the collapse of dams.
Wind energy	Wind parks	–	Visual impact, noise emission, impacts on birds, shadow flicker, land use, electromagnetic interference.
Solar radiation	Photovoltaic parks	–	Land use, visual impact.

Table 2
Wind turbine's emitted noise diffusion.

Emitted noise level from the wind turbine (dB)	Distance for noise level reduction at 45 dB	Distance for noise level reduction at 40 dB	Distance for noise level reduction at 35 dB
105	350 m	575 m	775 m
100	200 m	350 m	575 m
95	120 m	200 m	350 m

contrary, the installation of a wind park in a rocky area may not provoke the public opinion [13].

- **Several peculiarities of the installation area's surroundings**. The existence of popular tourist destinations or archaeological areas in the neighbourhood of a wind park's site may raise significant barriers during either the project's licensing procedure or the installation of the machinery.
- **The installed wind turbine's model and colour**. It is generally accepted that the use of tubular towers rather than lattice ones improves the visual impression of a wind park. Another significant parameter is the wind turbines' visual uniformity. The visual uniformity of a wind turbine is based on the uniformity of the rotor, the nacelle and the tower main dimensions. Wind turbines with three blades present an aesthetically improved picture. Finally, the colour of both the turbine's blades and the tower makes an important contribution to the visual integration of a wind park into the environment [9,13]. Wind turbines are usually coloured white or light grey. During the last years, a gradual transition from green (close to the earth) to white has been introduced.
- **The wind turbine's size**. The visual impact of a wind turbine reduces with the distance [14]. The visual impact of a wind turbine may be considered significant in distances lower than ten times its tower height. Inside this circular area the wind turbine dominates and the landscape is strongly affected. A wind turbine, under certain circumstances (clean atmosphere, lack of physical barriers), may be visible at distances equal to 400 times its tower height. This means that a wind turbine with a tower of 50 m height may be visible at distances of 20 km. However, at distances greater than 5 km, the wind turbine is gradually absorbed by the landscape, without affecting its aesthetic (Fig. 1).

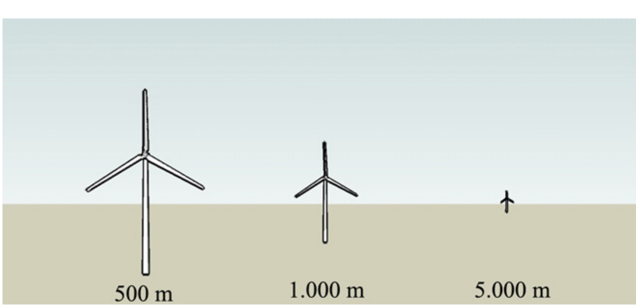

Fig. 1. The visual impact of a wind turbine versus the distance from its installation site.

2.2. Noise emissions

The wind turbines' operational noise is not intensive just a few hundred meters away from its source and it is usually masked by the noises produced by the wind itself. Moreover, areas where strong winds blow, namely areas appropriate for wind parks installations, are not usually chosen for the development of human activities (residential or industrial areas).

The noise produced from a wind turbine is divided into the aerodynamic and mechanical noise.

The aerodynamic noise emissions depend on the blade's aerodynamic design and the wind velocity. The aerodynamic noise is treated during the design of the turbine's rotor. It consists of the rotation noise and the turbulence noise [15].

The rotation noise includes noises with frequencies harmonics of the rotor's rotation frequency. The rotation noise emissions level increases with the rotor's diameter, the reduction of the blades' number, the blades' angular velocity and the blades' aerodynamic load (increase of the captured wind energy).

The turbulence noise is produced by the vortex at the edge (tip) of the blades and the turbulence behind the rotor. The turbulence noise reduces with the reduction of the blades' angular velocity, namely with the reduction of the produced power.

During the last two decades extensive research has been carried out in the field of aerodynamic design of the wind turbine's blades, with main targets the increase of the produced power, the reduction of the blades' mechanical loads and the reduction of the aerodynamic noise emissions. As a result, the aerodynamic noise emissions from the modern wind turbines are less than 10% of the respective emissions from the wind turbines of the early eighties.

The wind turbines mechanical noise is caused by the moving electromechanical parts of the machine. The main sources of the mechanical noise are the machine's gear box, the electrical generator and the main shaft's bearings. The mechanical noise is treated either on its sources or during its diffusion with appropriate insulation techniques.

The noise emissions level from modern wind turbines ranges between 95 and 105 dB and mainly consists of the aerodynamic noise. The mechanical noise is remarkably reduced, with either the introduction of several noise insulation techniques, or the elimination of the machine's gear box. The mechanical noise in modern wind turbines may be detectable only in case of a machine fault. The aerodynamic noise is continuously reduced by the constructors, by improving the blades' aerodynamic design.

Several methods have been developed for the wind parks' noise diffusion calculation [16–18]. An accurate noise emission calculation may require special calculations for night time [19]. Typical

Table 3
Noise level emitted by several human activities or devices.

Human activity or device	Emitted noise level (dB)
Human speech	65
Electrical refrigerator	35–40
City centre	75
Night club	100
Bedroom during siesta	30

noise diffusion in terms of distance from a modern wind turbine is presented in Table 2.

The noise emissions level from several human activities or devices is presented in Table 3.

The upper limit for the wind turbines' noise emissions level in residential areas varies in different countries in the European Union. This limit is set in 45 dB in Denmark and in 40 dB in Greece and Sweden. In Great Britain this limit is allowed to be 5 dB higher than the average noise level in an area.

The wind turbines noise may be detectable only under certain conditions. In low wind velocities wind turbines do not operate, hence they do not produce noise. In wind velocities higher than 8 m/s the wind turbines noise emissions are covered by the several noises produced by the wind (tree leaves, etc.). The wind turbines' noise may be detectable only when the wind velocity ranges between 3 and 8 m/s. Even in this case, the noise diffusion is significant only in the direction in which the wind is blowing. A major factor that may affect the noise annoyance of people living close to a wind park is the visual contact with the source of noise [20].

2.3. Impacts on birds and wildlife

Fatalities of birds and bats caused by wind turbines were firstly recorded in the late eighties in the U.S.A. Specifically, it was observed that specially protected endemic bird species (golden eagles, hawks) were killed either by wind turbines or by high voltage utility network lines, in California's Altamont Pass. These facts directed the scientists' interest towards the study of this problem.

Generally, wind turbines affect birds in one of the following ways [21–24]:

- fatalities due to electrical shock
- fatalities due to collision with the turbines' spinning blades
- the installation of wind parks in important areas for birds, such as prey or procreation areas
- loss or disturbance of habitats in proximity to turbines
- the installation of wind parks in migration corridors.

There is a strong connection between an area and its birds' fauna. Birds usually depend heavy on their biotope and they are extremely sensitive to possible modifications that take place in it. On the other hand, there is a strong connection between an area and the optimum siting of a wind park, imposed mainly by the available wind potential and the land morphology of the installation site. A conflict between the optimum siting of a wind park and the conservation of a sensitive biotope is often met.

There are a considerable number of studies on the impacts of wind parks on birds. Generally, wind turbines, under specific conditions, can constitute a serious danger for birds. It is proved that areas with strong air streams are used as passages by birds, especially migratory ones. The installation of wind turbines in such areas creates a potential collision risk with birds [25]. Wind turbines installed in the vicinity of endangered species' biotopes can also constitute a serious threat [26–28].

On the other hand, several studies conclude that wind turbines do not constitute a serious threat for birds, mainly because birds, in general, have the ability to detect wind turbines in time and change their flying path early enough to avoid them [29–33]. Another argument is that wind parks affect birds significantly less than several other human activities [34].

Both categories of former studies conclude that, in order to eliminate the probability of harming the natural environment significantly, and especially birds, a wind park should be designed properly and all the possible impacts on birds should be examined with scrutiny beforehand [35–37]. The implementation of systematic pre- and post-construction studies to explore the potential impacts of wind parks on wildlife can contribute to the optimisation of the wind park siting, taking into account both the maximisation of the produced electricity and the conservation of wildlife. If necessary, special measures for the protection of birds must be introduced during the wind park's operation [25]. A general collaboration between the wind parks developers, the state and their agencies responsible for the wildlife can also contribute to the proper selection of wind parks installation areas.

For a better estimation of impact of wind parks on birds, the implementation of longer-term studies with extensive follow-up, based on systematically collected data according to standardized protocols is also suggested [24].

Further adverse effects on wildlife, except birds, can also be caused by wind parks. The infrastructure works required for the installation of a wind park alter ecosystems through the clearing of vegetation, soil disruption and the potential for erosion. These changes can be of major importance and lead even to habitat loss and fragmentation for forest-dependent species in case of a wind park planned to be installed in a forested area [33]. On such occasions, changes in forested ecosystems may considerably affect its flora and fauna, although no deaths of animals may be directly caused by the wind park.

2.4. Shadow flicker from wind turbines

Settlements nearby to wind parks may suffer from the wind turbines' shadow flicker for certain time periods during a year. The turbines' blades cast a shadow on the neighbouring area when the sun is visible. When the turbine's blades are rotating, they cast moving shadows across the landscape and houses. At a constant point this is experienced as a flickering as the blades pass in front of the sun, causing an undesirable or even disturbing feeling [38–41].

The possibility for suffering from a wind turbine's shadow flicker is much higher for wind parks installed close to residential areas. According to the Hellenic legislation, the minimum distance between a wind park and a settlement is 500 m. This distance restricts the possibility for a settlement to suffer from a turbine's shadow flicker. The shadow of a turbine's blade fades through the atmosphere and it is practically invisible after a specific distance. Theoretically, the shadow of a 22 m long turbine blade may be visible up to a distance of 4.8 km. This may occur just a little after the sunrise and just a little before the sunset. Practically, for a 3 MW wind turbine, with a blade of 45 m length and 2 m width, the shadow of the spinning blade may be visible up to a distance of 1.4 km, although some weak shadow casting may be observed at a distance of 2 km [38–41].

Another major parameter, except distance, is the flicker frequency. Flicker frequency is the critical factor for serious human diseases [41] and should be kept to a maximum of three blade's passes per second, namely sixty revolutions per minute for a three-bladed turbine. Additionally, turbine blades should not be reflective.

From sunset to sunrise, the shadow of a wind turbine follows the route of a sundial, beginning from west and ending to the east. Since the positions of sunrise and sunset change during the year, the daily route of a wind turbine's shadow is not the same for different time

Table 4
Land occupation for electricity production from different technologies.

	Biomass	Nuclear	Coal	Natural gas	Hydro	PV	Wind
Land occupation (m^2 years/GWh of produced electricity)	380,000	300,000	1290–25,200	4200	2350–25,000	9900	2040

periods during a year. Consequently, it is obvious that a specific point on earth will suffer from a wind turbine's shadow flicker for only a very specific time period at a very specific moment during the year. Moreover, taking into account that the sunrise and sunset positions at a certain region on earth are known during a year, the moment and the period during which a specific point on earth will suffer from a wind turbine's shadow flicker may be predicted [40]. Computer models in wind development software can determine the days and times during the year that specific buildings in close proximity to turbines may experience shadow flicker.

It is obvious that you cannot avoid shadow flicker after the construction of a wind farm, unless you prevent wind turbines' rotors from rotating. Shadow flicker from wind turbines can be predicted and avoided only with the appropriate design of the siting of a wind farm. The abovementioned software tools can contribute towards this direction. The positions of the nearby habited settlements should be taken into account and the minimum distances from them, as defined in the national legislative frameworks, should be kept.

2.5. Use of land

A very common argument is that wind parks require more land than the conventional power plants (thermal and nuclear) to produce the same quantity of power, namely they exhibit lower power density. However, after a more thorough analysis, it is revealed that the above thesis is not indubitable. Both the thermal and the nuclear power plants require significant amount of land for several procedures that take place before, during and after the power production. These procedures may be the mining or the pumping of the fuel, the fuel's transportation, the fuel's preparation process and storage, the storage or the disposal of the production waste, etc. For the above procedures mines, oil refineries, ports, storage premises and power plant stations are all used. Except for the abovementioned places, large amounts of land in proximity to the thermal or nuclear power stations are strongly affected by their operation and, often, they become uninhabitable for humans or animals.

According to former studies, approximately 200–5000 m^2 of land per MW of installed wind power are required [42]. If wind turbines with nominal power higher than 2 MW are used, the above figures are lower. Practically, the land occupied by a 3 MW wind turbine is a square around the turbine of $40\,m \times 40\,m = 1600\,m^2$. Only inside this area no activities may be fulfilled. Except for this specific area, the remaining land of a wind park may be used for other activities too.

Table 4 summarizes the land occupation for power production using different conventional or renewable technologies [43]. The land occupation, as presented in Table 4 involves the duration over which the area of the transformed land returns to its original state (reclamation period), measured as a product of land area (m^2) and time (year).

As shown in Table 4, biomass farming (willow, high-pressure gasification) entails the greatest land occupation, 380,000 m^2 year/GWh, followed by nuclear-fuel disposal, 300,000 m^2 year/GWh (=30 m^2/GWh × 10,000 years of reclamation). The land occupation of surface coal mining varies between 1290 m^2 year/GWh (43 m^2/GWh × 30 years of reclamation), and 25,200 m^2 year/GWh (840 m^2/GWh × 30 years of reclamation). The land use for a natural-gas power plant is estimated 4200 m^2 year/GWh (140 m^2/GWh × 30 years of reclamation). A PV power plant with 13% efficient modules requires 9900 m^2 year/GWh of land occupation. A wind park with a capacity factor of 36% requires 2040 m^2 year/GWh of land occupation. Finally, the land required for generating hydroelectric power varies significantly according to site-specific conditions (from 2350 to 25,000 m^2 year/GWh).

2.6. Electromagnetic interference

Problems related to wind turbines' electromagnetic interference are caused by [44]:

- the location of wind turbines in relation to existing radio or television stations that can influence the signal transmission
- possible electromagnetic emissions produced by the wind turbines themselves.

The transmission from radio or television broadcast frequencies (mainly FM broadcast frequencies) is influenced by obstacles between the transmitter and the receiver. The main problem created by wind turbines is caused by the moving blades which can result in signal variations due to deflection. This effect was more of a problem with first generation wind turbines which had metal blades. The blades of modern wind turbines are now made exclusively of synthetic materials which have a minimal impact on the transmission of electromagnetic radiation [44–46].

According to the Hellenic legislation, a license for a wind park will only be granted if some minimum distances are kept from telecommunications or radio and television stations. Problems related to wind turbines' electromagnetic interference can be prevented by proper design and location of wind parks. The installation of additional transmitter masts, if required, can also be a solution, with low additional cost for the wind park investors [44–48].

As far as the wind turbines' electromagnetic emissions are concerned, the only subsystems of a wind turbine which could possibly "emit" low level electromagnetic radiation are the electric generator and the medium voltage transformer. The electromagnetic field of a wind turbine is extremely weak and is confined to a very short distance from the exterior turbine housing which is at least 40–50 m above the ground [44,47,48]. Consequently, there is no exposure to electromagnetic radiation at all, and especially not at the base of the wind turbine.

3. A case study for the Prefecture of Lasithi, Crete

The Prefecture of Lasithi is the most eastern Prefecture of Crete, with a population of 76,319 people (in 2001) and an area of 1823 km^2. The remarkable wind potential of Lasithi Prefecture is depicted in the Prefecture's wind atlas in Fig. 2 [49]. Wind parks with a total nominal power of 95 MW were installed in Prefecture at the end of 2007. This figure corresponds to the 68% of the total wind power installed in Crete at the end of 2007. The installed wind parks' sites in Lasithi Prefecture are presented in Fig. 3 [50].

As seen in Fig. 3, most of the existing wind parks are installed in the eastern part of the Prefecture of Lasithi. In the Municipalities of Sitia and Itanos the density of the installed wind turbines is

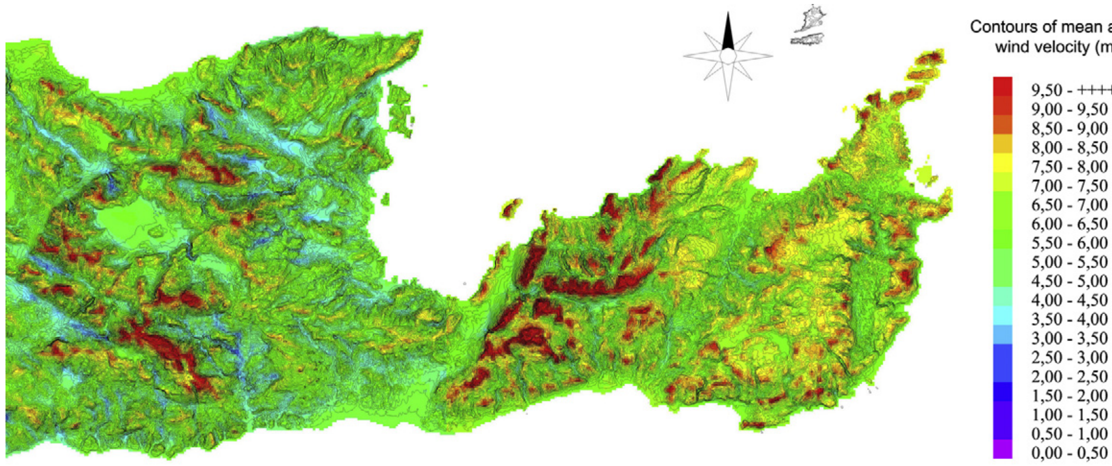

Fig. 2. Contours of the mean annual wind velocity (m/s) at 10 m above ground level (a.g.l.) on Prefecture of Lasithi.

calculated as equal to 0.1561 and 0.1452 wind turbines per 1000 m^2 respectively.

In the framework of a project entitled "Regional Wind Technology and Knowledge Transfer Strategies", financed by Interreg IIIC North, several studies were carried out on environmental and human impacts of wind parks in the Prefecture of Lasithi and the public opinion on wind parks in Crete. Specifically, the accomplished tasks are:

a. the estimation of visual impacts of four selected wind parks, installed in characteristic positions of the Prefecture of Lasithi
b. the estimation of noise emissions from the same wind parks
c. the implementation of a statistical survey on the public acceptance of wind parks and wind energy in Crete
d. the construction of a map with the optimum sites for wind park installation in the Prefecture of Lasithi, taking into account all possible restrictions concerning the use of land, the impacts on human life and the environmental conservation.

The tasks (a) and (b) from the above list were executed for the following wind parks:

a. The wind park at Agios Ioannis, installed at the western part of the Prefecture of Lasithi, only five kilometres northwest from the historical island of Spinalonga (it was a leper colony, officially defined and financed by the Hellenic State until the 1960s).
b. The wind park at Maronia, consisting of 55 wind turbines, with a nominal power of 27 MW, installed only 4 km south from the town of Sitia.
c. The wind park at Xirolimni, installed at the eastern part of the Prefecture of Lasithi.
d. The wind park at Handras, installed at the southern part of the Prefecture of Lasithi, just a few hundred meters north from the village of Handras.

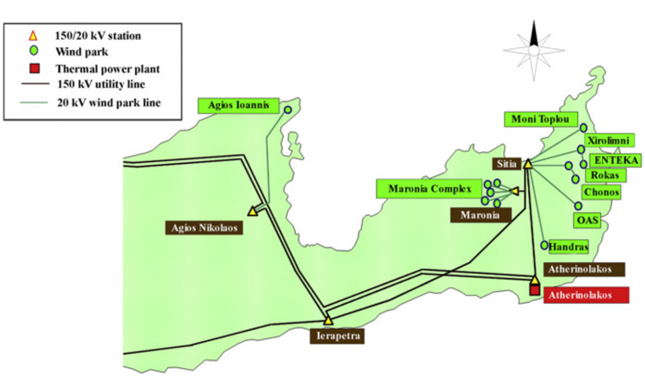

Fig. 3. The installed wind parks' sites in Prefecture of Lasithi.

These studies were implemented from 2005 to 2007 by the Wind Energy Laboratory (T.E.I. of Crete) on behalf of the Prefecture of Lasithi Authority. The results are presented below.

4. Visual impacts and noise emissions of the examined wind parks

4.1. Visual impacts

The visual impacts of the examined wind parks in the Prefecture of Lasithi were evaluated with:

a. The calculation of the visual impact zone of each wind park. This task was accomplished with the use of the Topos 43D software, Denmark. The visual impact zones were calculated to a maximum distance of 10 km from each wind park's installation site.
b. The construction of the installed wind turbines 3D models (Google Sketch Up) and the insertion of these models in Google Earth environment at each wind park's installation site. Several photorealistic views of the examined wind parks were captured from different points.

The results of the visual impacts evaluations are summarized in Table 5. In Table 5 the visual impact zones' percentages are calculated over the area of a circle with a 10 km diameter and its centre point on each wind park's installation site. The zones of partial visual impact include locations from which only a part of each wind park is visible.

In Figs. 4 and 5 photorealistic views of the wind parks at Agios Ioannis and Handras from the island of Spinalonga and the village of Handras are presented respectively.

From the fulfilled analysis, the following may be concluded:

The wind parks installed at Agios Ioannis and Maronia exhibit extended visual impact zones. This is due to the mild land morphology of the neighbouring area of their installation site. On the other hand, the zones of visual impacts of the wind parks at Handras and Xirolimni are restricted to specific directions by the high mountains located in the vicinity of these wind parks. The mountainous land morphology met in the most part of the Cretan territory restricts

Table 5
Summarized results from the wind parks' visual impacts evaluations.

Wind park	Zone of partial visual impact percentage (%)	Zone of full visual impact percentage (%)	Wind park visible from settlement or important place	Distance from settlement or important place (m)
Agios Ioannis	93.33	66.67	Island of Spinalonga	5000
Maronia	51.87	34.61	Town of Sitia	3500
Xirolimni	38.65	19.08	Monasteri of Toplou	5200
Handras	26.12	24.83	Village of Handras	800

the zone of visual impacts of the existing or the future wind parks in Crete.

The wind parks at Agios Ioannis and Maronia are visible either from historical sites or towns of Crete (e.g. island of Spinalonga, town of Sitia). In these cases, the wind parks do not seem to affect the visual aesthetic of the landscape due to the long distance of view that exceeds 3000 m (Fig. 4).

However, there are some small villages or uninhabitable settlements with direct visual impact with a wind park from distances lower than 1000 m. The village of Handras is mentioned as the most characteristic example. In these cases, the wind parks dominate and the landscape is certainly affected (Fig. 5).

4.2. Noise emissions

The noise emissions from the examined wind parks in the Prefecture of Lasithi were calculated with the ECHO software, developed in the Wind Energy Laboratory according to the standard ISO 9613-2, 1996 [51]. The results of the executed calculations are summarized in Table 6.

In Fig. 6 the noise diffusion graph from the wind park at Maronia is presented, as an example of the carried out calculations.

From the calculations it is concluded that there are some villages in Prefecture of Lasithi that under certain wind conditions, mentioned previously in Section 2.2, may suffer from wind park noise emissions of a maximum level of 40–42 dB. This noise disturbance may be present although the minimum distances of the wind parks installation sites from the nearby settlements, as defined in the relevant Hellenic legislation, are kept.

The time percentage over a year during which the nearby settlements to the examined wind parks may suffer from wind turbine noise can be calculated using the wind roses data at the examined wind parks sites. Such data are derived from the wind velocity measurements, available from the wind parks sites at Agios Ioannis, Handras and Xirolimni. The available wind roses are presented in Fig. 7. Using these data, the time percentage over a year during

Fig. 4. Photorealistic view of the wind park at Agios Ioannis, captured from the island of Spinalonga (distance of view 5000 m).

Fig. 5. Photorealistic view of the wind park at Handras, captured from the village of Handras (distance of view 800 m).

Table 6
Summarized results from the wind parks' noise emissions calculations.

Wind park	Nearest settlements	Distance from the nearest wind turbine (m)	Settlement position relatively to wind park	Wind blowing directions affecting the settlement	Time percentage during a year of noise disturbance (%)	Maximum noise level (dB)
Agios Ioannis	Mironikitas	1179	W	E, NE, SE	3.19	35.0–40.0
	Vrouhas	1436	SW	NE	0.19	35.0–40.0
Xirolimni	Palaio Mitato	588	SW	E, NE	1.15	37.5–42.5
	Vrisidi	1319	S	N, NW, NE	7.16	27.5–32.5
Handras	Handras	1148	SE	NW	15.14	32.5–37.5
	Armenoi	1065	S	N, NE	14.75	40.0–42.5
	Voroi	1874	W	E, SE	1.04	35.0–37.5
Maronia	Skordilo	907	SW	NE, E	2.56	35.0–40.0
	Epano Kra	658	SW	NE	0.77	27.5–30.0
	Parasporoi	1655	NW	SW, S	3.43	27.5–32.5
	Ahladia	825	N	S, SE, SW	10.52	35.0–37.5
	Epano Episkopi	1908	SE	NW, W	37.93	27.5–30.0
	Agios Georgios	1729	SE	NW	37.09	25.0–30.0

which the wind is blowing from a specific direction, transferring the wind turbines' noise to a nearby settlement, may be predicted accurately. Table 6 summarizes these calculations too.

A common conclusion from the above analyses is that the wind parks' visual or noise impacts on small mountainous settlements in Crete are almost impossible to be completely avoided, due to the large number of such settlements dispersed in the mountains of Crete. These settlements are also possible to suffer from the shadow flicker, for short time periods during the year, as explained in Section 2.4.

No town or site of historical or cultural value in the examined territory is affected by any kind of wind park impact. The impacts of wind parks in such areas can be avoided in the future, as well, with the proper selection of the wind parks' installation sites. The map presented in Section 6 aims to contribute to the achievement of this goal.

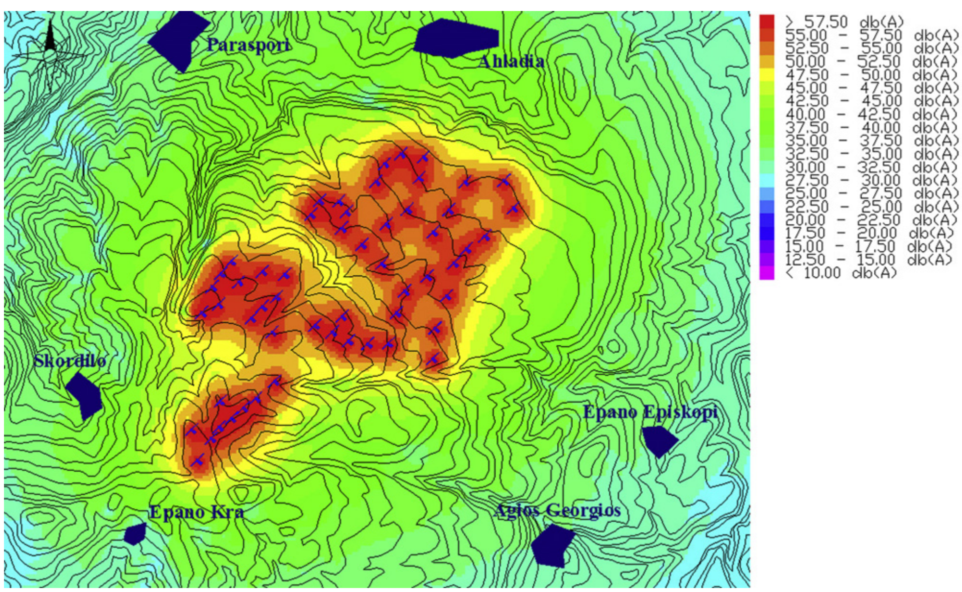

Fig. 6. Noise emissions from the wind parks installed at Maronia.

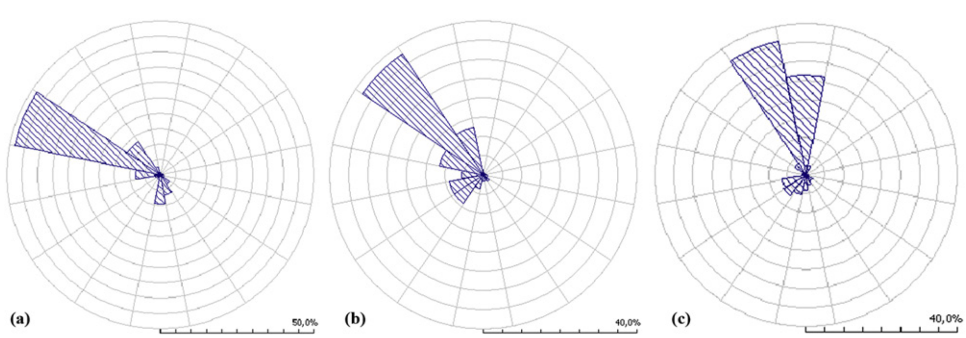

Fig. 7. Wind roses for the examined wind parks at Agios Ioannis, Handras and Xirolimni.

Table 7
Analysis of statistical survey sample.

Prefectures of Crete	Geographic origin	Number of citizens	Academic education		Age		Residents close to W/P		Total
			Yes	No	<50	>50	Yes	No	
Chania	Town of Chania	6	5	1	3	3	0	6	21
	Province	15	4	11	5	10	2	13	
Rethimno	Town of Rethimno	7	5	2	4	3	0	7	12
	Province	5	0	5	2	3	0	5	
Heraklion	Town of Heraklion	14	10	4	7	7	0	14	31
	Province	17	10	7	9	8	8	9	
Lasithi	Town of Agios Nikolaos	10	7	3	5	5	10	0	36
	Province	26	5	21	13	13	26	0	
	Total		46	54	48	52	46	54	100

5. Public opinion on wind energy and wind parks in Crete

A statistical survey on the public opinion on wind energy and wind parks in Crete was implemented in 2006. A sample of 100 people was selected, including:

- residents of towns and villages
- people of different ages
- people of different educational levels
- people living close to an existing wind park or not.

The statistical survey sample is analysed in Table 7. The sample was distributed in Crete's four Prefectures in terms of their permanent populations. People from towns and villages were included in the sample, taking into account both the provinces' populations and the existence of operative wind parks. Approximately half the people of the sample were under 50 years old and had an academic education (university graduates). Finally, the 40% of the sample live permanently in the vicinity of a wind park (within a distance less than 5 km).

The survey is divided into three parts. It starts with general questions on wind energy, such as:

i. What is your opinion about the electricity production from wind energy?
ii. To which percentage do you think that wind energy should contribute to the annual electricity production in Crete?
The second part investigates whether the citizens in Crete are or feel efficiently informed about wind energy. Some characteristic points are:
iii. Which are the main advantages (disadvantages) resulting from the operation of wind parks?
iv. Do you feel efficiently informed about wind energy and wind parks?
The survey is completed with the third part that examines the acceptability of wind parks and wind energy in Crete:
v. How much do you think that the percentage of citizens in your community that accept a wind farm in their area is?
vi. How far from a town or a village do you think that a wind park should be installed in order not to disturb?
vii. How many wind turbines could be installed close to a town or a village without disturbing?
viii. Are you willing to pay a higher electricity price for the electricity produced by wind parks?

Some of the most interesting results of the questionnaire are presented in Fig. 8.

From the results presented in Fig. 7, the following can be mentioned:

The residents in Crete strongly support the development of wind parks in Crete and are willing to accept wind energy as the main energy source for the electricity production in the island, instead of conventional energy sources, like oil, coal or nuclear power (questions I–III). It is worth mentioning that there was not even one among the participants in the survey with a negative opinion concerning wind parks or wind power (question I). These attributes stand even though the 40% of the participants have a direct contact (visual or acoustic) with an existing wind park.

Another interesting issue is that the participants in the survey believe that the majority of the residents in Crete would accept a wind park in their area without objections (question IX). This fact, combined with the results of question IV, reveals the following conclusions:

a. people in Crete support the maximization of the wind power penetration and the limitation of imported fossil fuel consumption in the electricity production sector, taking into account both the environmental benefits of wind power and the necessity for conventional energy sources safe
b. people in Crete either do not consider the wind parks' environmental impacts of major importance, or they are willing to tolerate them in favour of an independent, alternative and environmentally friendly energy future for their island.

The main disadvantage occurring from the operation of wind parks is considered to be the noise emissions. The impacts on birds come second and the visual impacts third (question V). The interesting result in this part of the survey is that one of the major disadvantages of wind parks is considered to be their inefficient operation. This result verifies the argument that an operative wind park may be more easily accepted than one that stands still. Once the above four types of impacts are restricted, the acceptability of a wind park in Crete is expected to be high.

The distance of a wind park from a town or a village should be 3000 m in order not to disturb (question VII). On the other hand, the number of the wind turbines that can be installed close to a village or a town without disturbing is unlimited (question VIII). These results lead to the following conclusions:

a. people in Crete do have a clear and logical opinion on the minimum required distance of a wind park from a settlement, in order not to disturb
b. the impacts of a wind park installed close to a town or a village are not considered important compared to the necessity or the willingness to exploit the maximum possible percentage of the available wind potential in a site.

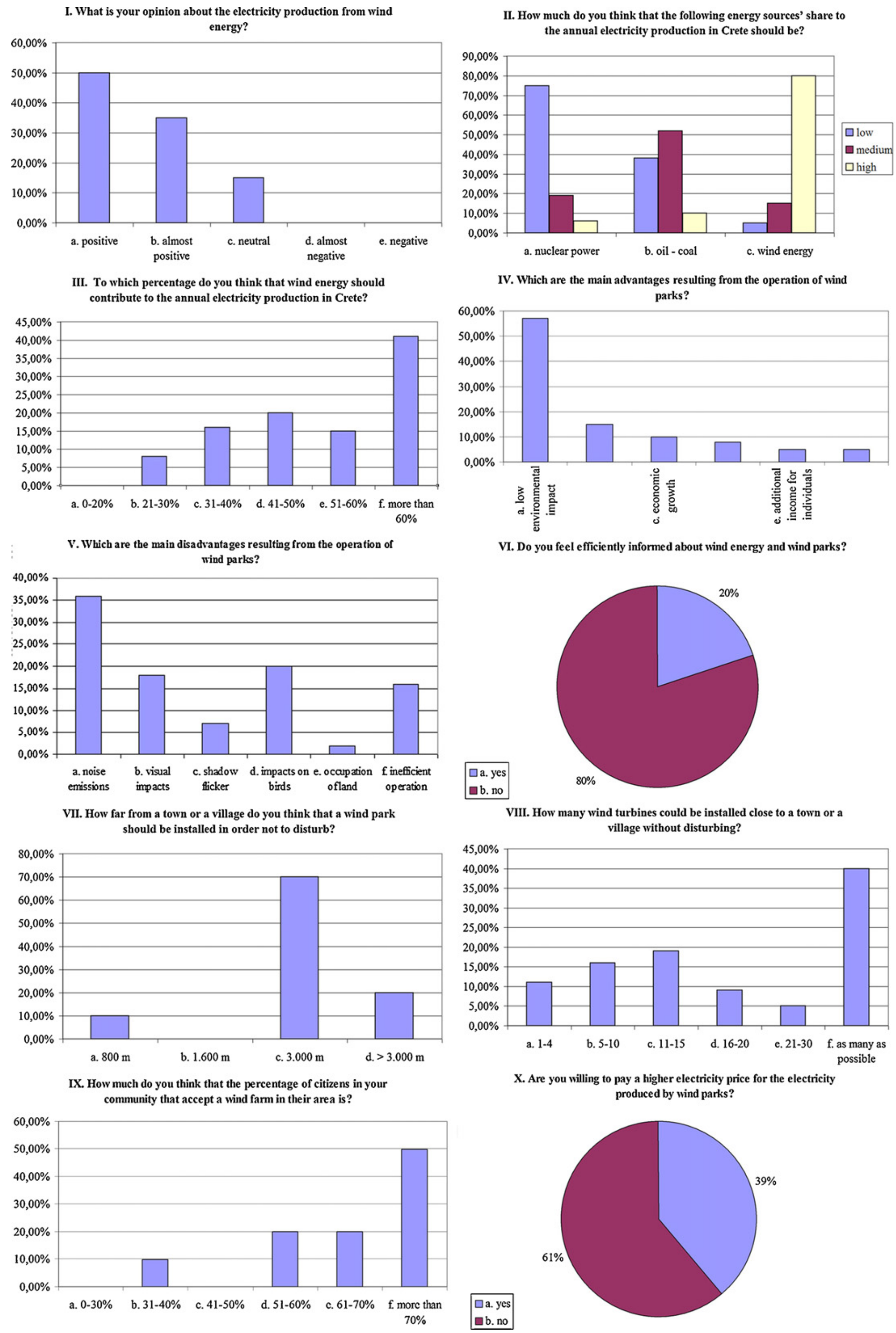

Fig. 8. Synoptic results of the statistical survey on public opinion on wind energy and wind parks in Crete.

Most of the residents do not feel well informed about wind energy and wind parks (question VI). This feeling is presented despite the promotion policies on Renewable Energy Sources, adopted and applied in the European Union during the last decade. Perhaps the Hellenic state or the Cretan local authorities should proceed to the implementation of further appropriate information campaigns on wind energy and its modern applications both on a large and small scale.

Finally, despite the positive public opinion on wind parks and wind power in Crete, most residents are not willing to pay a higher price for the electricity produced from wind parks (question X). However, we must accept that this result is partially configured by

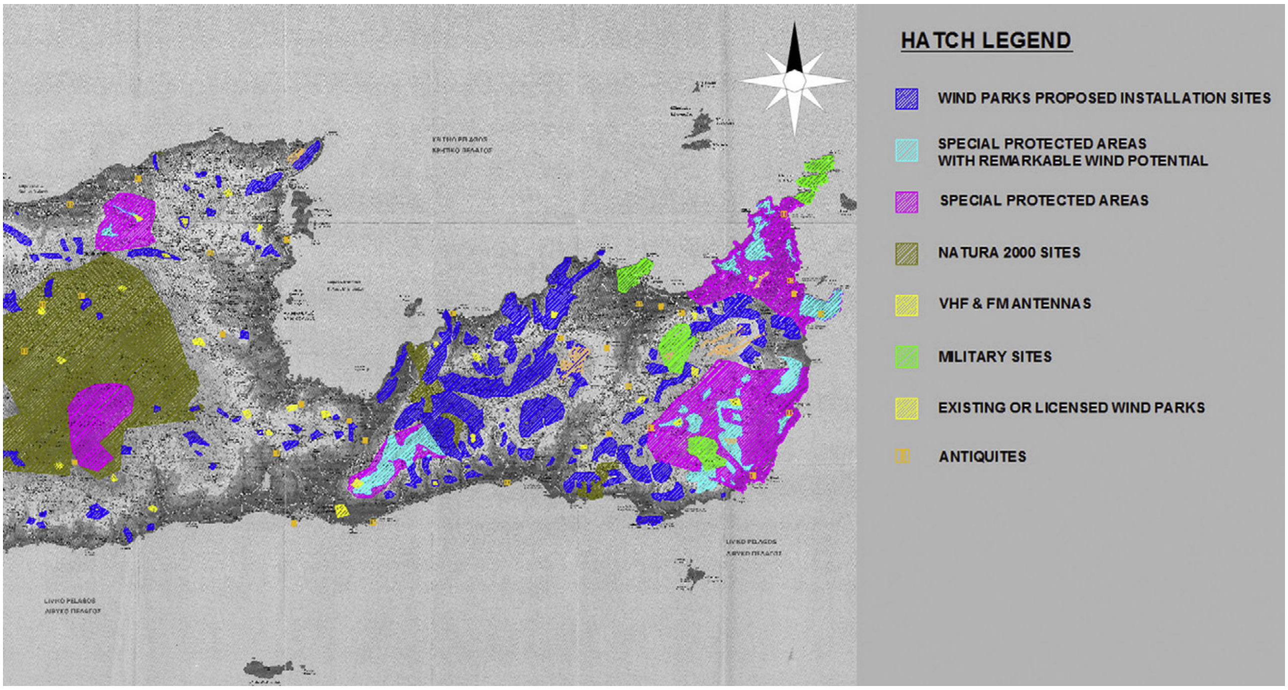

Fig. 9. The map of wind parks' optimum installation sites in Prefecture of Lasithi.

the economic conditions of the average Cretan household and not only by the residents willingness to support wind energy. Besides, it must be noted that a quite high percentage of the participants in the survey, almost 40%, would not object to paying higher electricity costs in favour of wind energy.

6. The map of optimum wind parks installation sites in the Prefecture of Lasithi

A map with the optimum sites in the Prefecture of Lasithi for the installation of wind parks was constructed. All possible restrictions, regarding the use of land, the environmental conservation and the impacts on human life were taken into account. Such restrictions may be impacts on wildlife, impacts on existing services (airports, antennas, etc.), visual and noise impacts on archaeological monuments, tourist destinations, residential areas, etc. These restrictions, if not taken into account during the selection of a wind park's installation site, can either prolong the implementation schedule of the wind park's project during both its licensing and installation stage or affect negatively its normal operation.

The map was constructed both by gathering information from specialized maps and electronic databases [52–56] and by direct information inquiry from the appropriate public or private sector services (civil services or authorities, natural history museums, etc.).

The general lines of the map's construction procedure were:

- the wind atlas of the Prefecture of Lasithi was initially constructed and the sites with remarkable wind potential were marked
- the following areas were also marked:
  - NATURA 2000 sites
  - Special Protected Areas regarding birds fauna or wildlife in general
  - historical and archaeological sites
  - areas with military premises
  - areas of tourist interest
  - sites with FM and AM antennas
  - residential areas.
- the latter areas were subtracted from the former ones, in case of coincidence
- the remaining areas with remarkable wind potential are proposed as the wind parks' optimum installation sites in the Prefecture of Lasithi.

The constructed map is presented in Fig. 9.

The map of wind parks' optimum installation sites in the Prefecture of Lasithi aims to provide a decision tool for the investors and the public authorities for fast and optimum selection of candidate sites for new wind park installations. Three main benefits are expected with the use of the constructed map:

a. The new wind parks' impacts will be eliminated.
b. The wind parks projects licensing procedures will be shortened, since all possible licensing barriers will have been investigated in advance.
c. Once this map is publicly available, citizens of the Prefecture of Lasithi will have the opportunity to be confirmed that no wind park with possible serious impacts will be installed, if the installation site is among the proposed areas. In this way, the installation of new wind parks will not change the existing positive public opinion in Crete concerning wind energy and its applications.

It is important to note that the constructed map is not static, since the construction data are potentially changeable. Once the data used for the development of the map change significantly, the above described work should be accomplished again and the map should be updated. Another major issue is that the fulfilled work did not include the ownership status of the proposed optimum sites. Such a task could not be incorporated in the framework

of an academic project. This issue is to be faced by the wind parks' investors.

7. Conclusions

The wind parks environmental and human impacts are investigated in this article. The aim of the article is to evaluate the wind parks' impacts and to investigate the prerequisites for a wind park's mild and secure operation. This is achieved with the following tasks:

- an extended research on the most recent available bibliography and a review of the widely studied wind parks' environmental and human impacts worldwide
- a case study in the Prefecture of Lasithi, that included visual impacts evaluation and noise emissions calculations for four characteristic existing wind parks in the Prefecture and a statistical survey implemented in Crete on the public opinion on wind parks and wind energy.

The conclusions from the above tasks are summarized below:

None of the wind parks' environmental or human impacts may be considered as crucial for the environmental conservation and existence of life in planet. No comparison can stand to the corresponding environmental impacts of the conventional electricity production technologies (thermal or nuclear power plants). The effect of the wind parks' environmental impacts is always local and does not exhibit a global attribute, like conventional energy sources (oil, coal, nuclear power).

All possible environmental or human impacts of a wind park may be restricted or even eliminated with the optimum installation site selection and the appropriate wind turbines siting. The installation site selection should take into account:

a. The minimum required distances of the wind park from the nearby settlements, as defined in the relevant legislation, and their orientation relative to the wind park's position, in order to restrict the wind park's visual impacts, noise annoyance and shadow flicker. These impacts cannot negatively affect the progress of a wind park's project, on the condition that all prerequisites defined in the relevant legislation are kept.
b. The predefined minimum distances of a wind park from the nearby settlements may not guarantee the maximisation of its local acceptability. To achieve such a goal, special case studies should be implemented before the wind park's installation, in order to investigate possible impacts on the nearby human communities in advance. A statistical survey could also help. The wind park should be installed taking into account all the possible objections and anticipations of the local communities as derived from the fulfilled survey. With these actions, a wind park will probably be widely accepted. Proper dissemination and promotion campaigns could help towards this direction as well.
c. The determination of the installation area as a NATURA 2000 site or a Special Protected Area for bird fauna or wildlife, especially the existence of rare species concerning the bird fauna in the proximate area. Special measures, if required, should be introduced for the protection of the rare species and their secure co-existence with the wind park. Sites close to sensitive biotopes and routes of migratory birds, as well as forested areas, should not be used for wind parks' installations. The above measures will guarantee the elimination of possible harmful impacts on birds and wildlife.
d. The existence of sites with historical or cultural value and tourist resorts at distances less than 2000 m from the wind park's site. The visual impacts, the noise annoyance and the turbines' shadow flicker are usually unacceptable in such cases.
e. The existence of radio or television stations in the vicinity of a wind park's installation site should be investigated in advance. Appropriate distances from these stations should be kept.

The investigation of the abovementioned points during the selection of a wind park's installation site will eliminate the possible problems during the licensing or the installation of the wind park's project. A useful guide for evaluating wind parks projects beforehand is provided in the attached reference [34].

Especially in Crete and generally in regions with similar ecosystem and land morphology:

- The mountainous Cretan territory restricts the zones of visual impacts of wind parks. Exceptions may be met in some limited areas with mild land morphology.
- The big number of small villages or settlements dispersed in the Cretan mountains, implies that it is impossible to completely avoid any wind park's visual or noise impact on anyone of them, although the minimum distances between the wind parks and the settlements, as defined in the relevant legislation, are kept. These settlements may suffer from the shadow flicker for short time periods during the year.
- In the Prefecture of Lasithi, despite the high installed wind power, the visual impacts or the noise emissions of anyone of the operating wind parks do not affect any town or site of historical or cultural importance. This has been achieved with the proper selection of the wind parks' installation sites.
- The statistical survey in Crete revealed the positive public opinion towards wind parks and wind energy, despite the fact that a high percentage of the local population (40%) has direct experience of a wind park's visual impacts and noise emissions. This is mainly based on the doubtless environmental benefits arising from the wind parks' operation, concerning the limitation of gas emissions and the treatment of the greenhouse effect, as well as the limitation of the imported fossil fuel for electricity production in Crete.
- According to the survey's results, in order to ensure the acceptability of a new wind park, the following prerequisites must stand:
  - the noise emissions in the nearby settlements should not exceed the predefined upper limits
  - no impacts on birds or wildlife should be caused
  - the visual impacts on landscapes with special aesthetics or sites with historical, cultural or tourist value should be limited
  - the wind park should operate continuously and efficiently, namely the owners should guarantee its availability with its proper maintenance.
- Although the survey proved that people in Crete have clear knowledge about wind energy and wind parks, they do not feel well informed about this issue. Well-organized campaigns for the promotion of wind energy in Crete and worldwide will further improve public opinion and make wind energy more popular.
- Despite the positive public opinion concerning wind parks and wind power in Crete, most residents are not willing to pay a higher price for the electricity produced by the wind parks. This result is partially configured by the economic conditions of the average Cretan household and not only by the residents' willingness to support wind energy.

The present work was integrated with the construction of a map with the optimum sites for the installation of wind parks in the Prefecture of Lasithi. The map was designed by taking into account all possible restrictions that may be faced during either the licensing,

the installation or the operation of a wind park. This map may constitute a practical tool for the investors and the public authorities for the optimum site selection for a wind park installation, contributing to the limitation of new wind parks' environmental and human impacts, to the minimization of the required licensing time and the elimination of possible public reactions.

Acknowledgements

The author gratefully acknowledges:

- Interreg IIIC North for the financing of the project "Regional Wind Technology and Knowledge Transfer Strategies", within its framework the case studies for the Prefecture of Lasithi were accomplished.
- Prefecture of Lasithi Authority, and especially Mr. Emmanouel Zacharenakis, Head of Design and Development Office, for our excellent collaboration.
- Mr. Georgios Sartzetakis, Mechanical Engineer of the Technological Educational Institute of Crete, for his contribution to the map construction with the optimum sites for the installation of wind parks in the Prefecture of Lasithi.
- Mrs. Anna Spanou and Mrs. Katerina Helidoni, Mechanical Engineers of the Technological Educational Institute of Crete, for their contribution to the implementation of the statistical survey about the public opinion in Crete concerning wind energy and wind parks.
- Dr. Gareth Owens for his assistance.

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